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**The influence of content knowledge on pedagogical content knowledge – the case of teaching photosynthesis and plant growth**

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## Abstract

The aim of the research was to investigate the effect of the amount and quality of content knowledge on pedagogical content knowledge (PCK). The biological content photosynthesis and plant growth was used as an example. The research sample consisted of 10 primary and 10 secondary (biology) teacher students. Questionnaires, lesson preparation task and an interview were used to collect data. Primary student teachers' were not aware of students' conceptual difficulties and had problems in choosing the most important content. Neither of the groups had knowledge on suitable experiments and demonstrations, which indicates that PCK should be explicitly taught. The usefulness of PCK and some related constructs in initial teacher training is discussed.

*Keywords:* Content knowledge, Pedagogical content knowledge, Photosynthesis and growth of plants, Primary student teachers, Secondary student teachers, Teacher education

## Introduction

Lately teacher thinking has been the focus of research in finding out the components of effective teaching (Lederman & Niess 2001). According to the review article by Clark and Peterson (1986) the areas of teacher's thinking includes planning, implementing and the implicit theories behind the two phases. Shulman (1987) divided teacher cognition into seven categories of which pedagogical content knowledge (PCK) was novel and later very influential. It stressed the idea that much of teacher knowledge is content specific and has limited transfer to other situations.

In looking at the teacher thinking and action in a sequential way, the first part is teacher's practical theory (e.g. Ritchie, 1999), personal practical knowledge (e.g. Connelly, Clandinin & He, 1997) or implicit theory (Clark & Peterson, 1986). Teacher's practical theory (or knowledge) includes personal beliefs about the goals, values and principles of education. According to Connelly et al. (1997) this knowledge is not objective and independent of teachers as persons. In our view teacher's practical theory is very near to teaching orientation (Magnusson, Krajcik & Borko, 1999, Anderson & Smith, 1987) or teacher's epistemological beliefs (Hashweh, 1996).

The next type of knowledge needed by a teacher is a script how to perform a classroom session or lesson plan. The term script was used e.g. by Putnam (1987) and Borko, Livingston and Shavelson (1990). Scripts are composed packages of contents, goals and teaching methods. According to Aaltonen & Pitkäniemi (2001) scripts can be partly used as a synonym of PCK.

The next type of teacher thinking is the one implemented in classroom interaction. It informs the short-term decision making. It has become increasingly obvious that this micro scale and very rapid decision making should be included in studies together with analyses of teacher cognition. It seems that this thinking during the teaching concentrates more on students and the ways to act rather than the content (Marland & Osborne, 1990). Especially expert teachers concentrate on students (Hogan, Rabinowitz & Craven, 2003). Because classroom situations demand an immediate response, teachers' have no time to reflect, and decisions are mostly intuitive. Tigchelaar and Korthagen (2004) call the set of unconscious sources of behaviour in a specific situation, a Gestalt.

This study is concerned mainly about the middle phase of the sequence in teacher cognition and teaching act. The parts of the cognition – action - chain are not, however, separate. Different ideas and goals might also be in conflict and cause inner friction. The context of teaching might cause outer friction and the good abilities of the teacher are not realized in practice. Teachers try to reduce frictions and form a coherent whole of their levels of thinking. Theory and action are more congruent among expert teachers (e.g. Ritchie, 1999). "Ideally, there is a complete 'alignment' of the levels, which means that the teacher's behaviour, competencies, beliefs, identity and mission together form one coherent whole matching the environment." (Korthagen, 2004).

The idea of PCK has a long history (Smith & Girod, 2003; Bullough, 2001,) and its content varies a lot among researchers (Hashweh, 2005; Zeidler, 2002). We agree with Hashweh (2005) that a more inclusive concept is better. In this study we apply roughly Shulman's (1986) five aspects of PCK as modified by Magnusson et al.(1999): (1) conceptual problems of the students, (2) the core content in teaching (knowledge of curriculum), (3) knowledge of teaching methods, (4) knowledge on content specific assessment methods, and (5) orientations to teaching science.

Of these the assessment methods were not included in the study, because no actual teaching was done, and no one of the participants included assessment in their lesson plans.

In this study the effect of the amount of content knowledge (CK) on PCK was studied. Two groups of student teachers, which differed mainly in the amount and quality of content knowledge, both however being novice teachers, were compared. They were referred to as content novices and content experts. Usually expert – novice studies has been conducted by comparing teacher thinking within the same teacher category. The review of Hogan et al. (2003) deals with expert and novice content specialist (secondary) teachers within the framework of PCK. Expert and novice teaching among classroom (elementary) teachers has more rarely been studied in content knowledge perspective (e.g. by Smith & Neale, 1989), but the findings on secondary teachers are probably applicable also in primary setting.

The CK of content novices has been characterized piecemeal, less structured, and having more mistakes or inaccuracies. Content experts have more structured knowledge and they understand better the relationships between concepts. That is why their knowledge is more readily applicable to teaching. (Hogan et al., 2003; Gess-Newsome, 1999; Smith & Neale, 1989; Hashweh 1987).

Expert CK generally improves teaching. Experts are more aware of the conceptual difficulties among children (Halim & Meerah, 2002; Hashweh, 1987), but according to Mapolelo (1999) CK had no effect. Content experts have better understanding on what is most important in the curriculum (Sanders, Borko & Lockard, 1993). Weak CK affects teaching in several ways when teachers are trying to cover up their poor knowledge (Newton & Newton, 2001; Gess-Newsome & Lederman, 1995; Carlsen, 1993, 1992, 1991; Sanders et al., 1993; Hashweh 1987). Experts have a wider collection of alternative teaching methods (Halim & Meerah, 2002; Gess-Newsome & Lederman, 1995; Hashweh, 1987; Sanders et al., 1993, Smith & Neale, 1989).

The importance of CK on teaching performance is somewhat controversial and needs further studies. Most researchers agree that a certain minimum amount of CK is necessary for the development of PCK (e.g. Magnusson et. al., 1999; Smith, 1999). In a study by Schempp, Manross, Tan and Fincher (1998) on physical education teachers were not able to transfer expert teaching to unfamiliar content.

## Aims and design of the study

In this research teacher cognition is examined as a relationship between CK and PCK. The topic photosynthesis and plant growth was selected. Two student teacher groups were used: primary (generalist) student teachers and secondary (biology) student teachers. Both groups had roughly the same amount of pedagogical studies done and they thus differed mainly on the amount of subject content studies. Primary student teachers were called content novices; biology student teachers were called content experts. Their PCK was compared applying the lesson preparation method (Van der Valk & Broekman, 1999).

The study focused on finding out

- What differences are found in primary and secondary student teachers' CK?
- Does student teachers' CK influence their PCK (of conceptual difficulties of students, knowledge of curriculum, teaching methods and orientation in teaching)?

- What types of pedagogical problems student teachers face when preparing their lesson plans?
- What kind of educational needs do student teachers have?

*Participants*

The participants were chosen so that they differed in the amount of CK other factors remaining approximately the same. The participants were ten primary student teachers and ten subject teacher students (biology majors). The both groups were inexperienced novice teachers. The biology student teachers represented the whole class taking the pedagogical studies. The same amount of primary student teachers was asked as volunteers for this study. This set of students is not a sample, but there is no reason to believe that they differ markedly from other teacher students in Finland, because we have a very unified educational system. The biology student teachers had studied one to two years of biology, 45-150 European study points (ECTS) at the university. They had studied thoroughly the theme photosynthesis and plant growth during their first year studies where they followed the textbook Campbell & Reese (2002). The primary student teachers had studied neither biology nor environmental and natural sciences at university level. Their university studies in science does not concern very much on content but science education. The theme photosynthesis was only shortly mentioned during one practical session titled "teaching botany in primary school". The subject content knowledge is thus the separating factor for the student teacher groups. These two student teacher groups were on the same level in their pedagogical studies having studied 20 - 40 study points (ECTS). Both groups had very little teaching experience.

## Method

The method utilized for studying the PCK of student teachers was the lesson preparation method followed by interview (Van der Valk & Broekman, 1999). The details of procedure are given below.

Frederik, Van der Valk, Leite and Thorén (1999) have used the lesson preparation method when studying the PCK of physics student teachers in case of teaching temperature and heat. Oldham, Van der Valk, Broekman and Berenson (1999) have used the same method on mathematics student teachers' and primary student teachers' teaching of geometrical areas. Moreover, De Jong, Ahtee, Goodwin, Hatzinikita and Koulaidis (1999) have utilised the method when studying science student teachers' PCK in the case of teaching the phenomenon of burning. The current study uses the lesson preparation method with minor alterations for studying biology student teachers' and primary student teachers' PCK in teaching photosynthesis and plant growth.

*Lesson plans*

First the student teachers were invited to write individually a lesson plan for a two hour teaching period on the topic of photosynthesis and plant growth for grade 6 students (aged 12). In Finland primary teachers normally teach grades 1-6 and subject teachers from grade 7 onwards. The grade six was chosen for the target group because it suits as well for both student teacher groups. In Finland grades 5-6 can be taught either by primary or secondary teachers. They had one hour time to write the lesson plan without any books or other material available and they were looked after by the researcher all the time. They were instructed that during previous grades the topic had been introduced to students using "spiral- principle" meaning that each grade students had had deeper and deeper knowledge on this topic. They were asked to work fully independently and not to discuss with each others.  They were also told that they should later justify their choices.

*Questionnaires*

The lesson plan was followed immediately by two questionnaires. In the first questionnaire students' background information concerning their university studies as well as their teaching experience and familiarity with the topic were collected. The second questionnaire was concerned of student teachers' own understanding of plant growth and photosynthesis and their ideas of students' prior knowledge, alternative conceptions and learning difficulties within the topic. The latter questionnaire was placed after the lesson plan task so that it did not affect the lesson plan.

*Interviews*

The interviews took place within two weeks after the lesson plan. During the interview, the student teachers were encouraged to tell about their lesson plans and their difficulties in writing them. The purpose of structured interview (appendix 1) was to study the student teachers' CK, PCK, and difficulties in lesson planning, and anticipated problems in teaching, and perceived educational needs to perform successfully as a teacher. The duration of the interviews varied from 25 to 60 minutes depending on how much time student teachers wanted to have

## Analysis and results

In most cases the analysis and finding out the categories was quite straightforward. Fairly robust categories were used. That is why it was considered unnecessary to describe the process of analysis in detail and include e.g. text or interview transcripts, with some exceptions. For the same reason and to avoid repeating the analysis procedure and the description of the results was combined in the same section.

## Student teachers' content knowledge

*Knowledge on starting materials and products of photosynthesis*

Understanding which are the starting materials and products of the photosynthesis was analysed by means of the lesson plans, the questionnaire and the interview. The purpose was to find out if the student teachers had described the starting materials and reaction products of photosynthesis reaction scientifically correct. Based on their understanding three categories were formed:

*Scientific view.* They had described starting materials and reaction products correct, meaning they had mentioned water, light and carbon dioxide as starting materials and oxygen and sugar as products. They did not need to mention heat or nutrients.

*Partly deficient view*. One of the starting materials or reaction products was missing.

*Deficient and/or wrong view*. Two or more materials or reaction products were missing or totally wrong answers were given.

According to the available data there is considerable variance in student teachers' understanding of photosynthesis. Three out of ten of primary student teachers involved in this study fully understood photosynthesis. They had scientific understanding of the process meaning they had described all substances necessary in photosynthesis to produce organic substances sugar, starch and other carbohydrates. The other student teachers had conceptual shortages and/or misconceptions included in their descriptions of photosynthesis. The following types of problems were discovered: four student teachers did not mention carbon dioxide as a necessary starting material, three of them did not mention sugar as the reaction product and three had forgotten that oxygen was released in the reaction. Two student teachers thought that carbon dioxide was released in the process. As anticipated biology student teachers had good scientific understanding of the process of photosynthesis. Only two (out of ten) did not mention that oxygen was released in the process.

*Understanding the connection of photosynthesis and plant growth*

Understanding the connection of photosynthesis and plant growth was analysed using the lesson plans and the questionnaire. Two categories were formed:

*The connection between the photosynthesis and the plant's growth is understood.* They had understood at least one of the following facts: 1) sugar is the product of the photosynthesis reaction, 2) the plant stores the sugar produced in the reaction, 3) as a result of the photosynthesis reaction the plant grows or 4) through the photosynthesis the plant receives the energy for growing 5) the plant receives carbohydrates (sugar) for its growing or 6) the plant produces carbon compounds for growing its mass.

*The connection is not understood*. If none of these were mentioned.

When the connection between photosynthesis and plant growth was examined several shortages in CK of the primary student teachers were found out. Four student teachers pointed out, in answering questionnaire or in their written lesson plan, the connection of photosynthesis and plant growth. Either they mentioned that production of sugar is part of the growing process or construction materials of a plant or that the photosynthesis is essential for a plant's growth. Also some student teachers mentioned that the plant growth and the sugar produced and stored in this process were connected. Nine biology student teachers mentioned the connection between photosynthesis and plant growth. Photosynthesis was connected in plant growth either by connecting the sugar and plant growth or by mentioning that in photosynthesis carbohydrates that a plant uses as construction materials are formed. Some also mentioned that through photosynthesis the plant gains its energy needed for growing. On the other hand some student teachers described that the mass of the plant consists of carbohydrates produced through photosynthesis.

*The main source of the mass of the plant*

The understanding of the main source of a plant's mass was studied through the answers received from the interview. Three categories were found: a) Carbon dioxide, b) water, and c) nutrients. All the three categories contribute to the growth, but because the main source of mass was asked the carbon dioxide was the only accepted answer.

When looking at the content knowledge of student teachers we found out that nine biology student teachers understood the role of carbon dioxide as a main source of the mass of the plant. Only one of them thought that the main source was water. On the contrary only one of the primary student teachers understood that carbon dioxide is a main source of the mass of the plant. Seven of them had an opinion that it is water and two of them thought that the main source was the inorganic substances of the earth.

## Student teachers' pedagogical content knowledge

*Knowledge on conceptual difficulties of the students*

1) The student teachers' knowledge on the typical conceptual difficulties that students have concerning photosynthesis and plant growth was studied on the basis of their answers in the questionnaire. The answers were classified as follows: a) students confuse the plant's nutrition into animal's nutrition, in other words: they do not grasp that a plants makes their own food; b) students think that photosynthesis is an inverse respiration of a plant (carbon dioxide in and oxygen out), c) students do not realise that carbon dioxide is needed; d) students consider for example water or nutrients as the main source for a plant's mass, i.e. they do not know the importance of carbon dioxide.

Elementary student teachers did not realize any conceptual difficulties that students might face when studying photosynthesis and plant growth. According to the answers it was very difficult to them even to think about the possible difficulties. On the contrary eight out of ten biology student teachers were conscious at last one of the conceptual difficulty that students might face and three of them could mention two and one could mention three such kind of conceptual difficulties. Biology student teachers more commonly realized that the problem was students' insufficient understanding of the main source of plant mass and growth. In addition four biology student teachers understood that students have, in general, difficulties to understand carbon dioxide as the substance necessary for plant growth. There were only two biology student teachers in the whole group who understood that students might think that plants get their nutrition in the same way as animals. None of student teachers realized that some students can have conceptual difficulties in thinking that photosynthesis is an "inverse respiration "of plants (Cañal, 1999).

*The main teaching goals*

The main teaching goals (knowledge on curriculum) were studied through student teachers' interviews if the answers contained any phenomena according to which classifications were possible to make. The following categories were formed:

*The process of photosynthesis and growth.* The description included the photosynthesis process.

W*onder.* Fostering natural curiosity of students.

*Ecological importance on the earth*. Student teachers described the meaning of plants for the life of earth or wide understanding of photosynthesis was emphasized.

*The core content*. The student teachers mentioned some core content, e.g. plants make their own food, the meaning of carbon dioxide.

*No answer.* They could not mention the most essential content to teach.

Six primary student teachers were convinced that the one of the most important themes were photosynthesis and plant growth. Especially they emphasized understanding of connection between plant nutrition and products as well as the meaning of photosynthesis. They also emphasized the importance of understanding of the meaning of the environment for the plant growth as well as for its structure. Two student teachers emphasized the meaning of understanding plants' ecological importance. One student teacher also stressed how important students' natural curiosity and raising questions is for learning. One student teacher could not name the most important subject in primary science biology curriculum.

Part of student teachers' answers on the question of the most important topic was quite general but some of primary student teachers described the content more specifically. Also biology student teachers as well as primary student teachers emphasized that the most important topics in primary biology is basic ecological understanding. Four biology student teachers particularly stressed the importance of understanding the food chains. On the other hand three biology student teachers emphasized that the main important topics were the understanding of meaning of carbon dioxide as the mass source of the plant and/or understanding the difference between plant and animal nutrition. Three biology student teachers said that the topics connected to the photosynthesis and plant growth were the most essential contents in biology curriculum. Biology student teachers pointed out the most important content more often than primary student teachers.

*Teaching methods (educational activities)*

The activities chosen by the student teachers were studied using both the lesson plans and the interviews. First the activities of each student teacher were gathered into a table. Then the similarities in them were looked after and the activities were classified into nine categories: a) experimental work, b) drama, c) observing plant growth d) study of plant structure (with microscope), e) manuscript for an animation or a video, f) searching information from internet, books and other media and presenting it in different ways, g) fieldwork, h) watching a video, and i) small group discussions.

Primary student teachers chose the following activities: examining plant structure (4), searching information and presenting it in different ways (4), plant growing and observing its growth (3), drama (2), experimental work (2), small group discussion (2), and writing manuscript for animation (1). (Table 1).

Insert Table 1 here

Biology student teachers chose the following activities: experimental work (6), examining of plant structure (6), plant growing and observing its growth (4), fieldwork (2), watching a video (2), searching information and presenting it in different ways (1), and small group discussion (1).

The biology student teachers generally used more direct activities (e.g. experimental work, fieldwork and video presentations), while primary student teachers used more indirect activities (e.g. searching information). Maybe the most notable difference was that primary student teachers suggested creative activities such as drama or making animations which were not mentioned in any lesson plans of biology student teachers.

It is difficult to look at the activities through content since student teachers, especially primary student teachers, did not always clearly connect content and method. It is notable; however, that even though the necessity of carbon dioxide for the plant or its sugar production would appear in some group discussions or when presenting a drama, the student teachers were not able to present any experiment of demonstration to prove it. They however presented experiments for some other needs of plants. Two biology student teachers presented an experiment to demonstrate he release of oxygen in the photosynthesis reaction.

*Orientation to teaching*

The student teachers approach for the teaching was studied through the lesson plans and the interviews, where the student teachers described the activities in the classroom. The researchers then wrote descriptions of the lessons based on the material. There are many ways of classifying teaching orientations or strategies, e.g. the nine categories by Magnusson, Krajcik and Borko (1999) and four categories by Anderson and Smith (1987). It is common that a teacher uses several orientations. That was the case in this study also. The activity-driven orientation (Anderson & Smith, 1987) was evident in many primary student teachers but not predominantly. However, the participants could best be classified to two categories, constructivist and conceptual, according to Adams and Krockover (1997). Hashweh's (1996) two categories are rather similar although he calls them constructivist and empiricist. ). Using the term 'constructivist' does not mean any form of the many views about constructivism. We only use the same label as in the classification in Adams and Crockover (1997). The most important point in the analysis was whether the emphasis on direct transmission of correct knowledge was evident in the lesson plans or not. The interpretation, however, remains subjective.

a) *Constructivist teaching orientation* is characterized by criteria where teacher negotiates the understanding of key ideas leads students to reconstruct their ideas, use of student-centred teaching methods, etc. Similar features are found in guided discovery (De Jong et al., 1999), and in discovery (Anderson & Smith, 1987).

An example of one lesson description classified as constructivist:

*First lesson*: Teacher finds out students' prior knowledge by asking. Next students are potting plants in order to watch their growth later. They weight the amount of soil put to the pots. Half of the plants are put to light and half to darkness. Then follows a discussion about the needs of plants for growth. Teacher encourages the students to express their views.

*Second lesson*: Students weight the plants and pot soil planted last time. They also weight similarly a bigger plant. This is followed by a discussion of the source of the mass of the bigger plant. Both of the plants are left to the class to grow. The discussion is summed up in a diagram on the blackboard and students make notes.

b) *Conceptual teaching orientation* is characterized by the criteria where teaching concentrates in transmitting correct scientific ideas, predominant use of teacher-centred methods, cookbook investigations, etc. This orientation is similar to didactic (Magnusson et al., 1999, Anderson & Smith, 1987), content mastery/didactic (Smith & Neale, 1989) or transmitting (De Jong et al., 1999) teaching orientation.

An example of one lesson description classified as conceptual:

*First lesson*: Teacher motivates the students. She asks the needs of a potted potato she has taken with her to the classroom. Teacher leads the discussion with suitable questions. Teacher makes a graph of the potato plant and its needs to the blackboard and students make similar notes. Teacher finds out students ideas of photosynthesis by asking and makes new question as a reaction to students' answers. False knowledge is corrected immediately. Students add a formula of photosynthesis to their notes. The knowledge is then repeated by looking a video on the topic. Students study potato plants in small groups and learn how to study plants life.

> *Second lesson*: Students start their studies on plant life. They search knowledge from textbooks and other sources or with hands-on experiments or demonstrations. The teacher gives instructions how to work and arranges material for the students. In the end students present their findings to others.

Primary student teachers had mostly constructivist teaching orientation (7). None of them emphasized solely conceptual approach but three of them were mixtures of the two. Half (5) of the biology student teachers were mixtures of the two approaches, four were classified as constructivist and one as a conceptual teacher. There is thus a clear difference between the two groups. Primary student teachers were mostly constructivist teachers, while biology student teachers were mostly mixtures of the two. They might be thought to be in transitional stage between the two orientations.

**Problems in lesson planning**

The problems in lesson planning and imaginary carrying out the lesson were studied using the interview. Five categories were formed: a) content knowledge, b) knowledge on the students understanding of natural science, c) organisational constraints and time, d) motivation, e) class control.

The most common problem that primary student teachers faced was insufficient content knowledge: all except one of them informed that the lack of sufficient content knowledge influenced their planning of the lesson and probably would also make the real teaching difficult. Three of them also mentioned the problem of insufficient knowledge concerning students understanding of science. Two student teachers pointed out the problem of class control and one thought that motivation might be a problem. Furthermore three of them said that they had not enough time to carry out the lesson plan properly.

The most common problem that biology student teachers mentioned was their insufficient knowledge on students' scientific understanding. These problems appeared when they tried to figure out how students in sixth grade think about this topic and what kind of prior knowledge they have. Four of them also reported the problems of insufficient CK. Two of them also mentioned the possible motivation problems and that the topic might not necessarily interest students. One of them was also concerned on class control problems. Students might also become unmanageable during a teaching activity.

## Perceived educational needs

The interview was used to study the perceived educational needs of the student teachers. The data was handled as described before and the final classifications were formed: a) CK, b) knowledge of teaching methods (activities) of science (PCK), c) knowledge of students understanding of science (PCK), d) knowledge of the curriculum of science (PCK), and e) experience or observation of teaching in the primary school.

The most important educational need that primary student teachers mentioned was CK (4). Two of them, however, had the opinion that they could gain the knowledge needed by reading themselves. Another educational need they mentioned was the knowledge of different ways to demonstrate the phenomena and make the subject more concrete (3). One primary student teacher also stressed the knowledge of primary curriculum to be important and one mentioned the need for teaching experience and observing teaching in primary level. Biology student teachers mentioned the knowledge of teaching methods (5), teaching and observing teaching in the primary level (5), knowledge about students understanding of science (2), and knowledge about the science curriculum (2).

## Discussion

Table 2 summarizes the main results. These are further discussed below.

"Insert Table 2 here"

*Content knowledge*

This study revealed that primary student teachers had several problems when looking at the reaction of photosynthesis and teaching. The typical problems of these novice teachers were: more or less fragmented and insufficient knowledge, misconceptions and difficulties to understand the connections between different concepts. These results are supported by Ekborg's (2003) study of student teachers' partial understanding of photosynthesis and plant growth. They confirm the results of Hashweh (1987) who pointed out several misconceptions and inaccuracy of content novice teachers. Also Smith and Neale (1989) pointed out that according to their study content novices had very inaccurate knowledge of photosynthesis.

Biology student teachers, on the contrary, had the knowledge on the topic that is typical for content experts: they had less misconceptions and inaccuracy than the content novices. They understood the connections between different concepts which are typical for content experts. Most of them also had a coherent model on the content in question. Content experts also had misconceptions and inaccuracies similar to those of content novices but the amount was much smaller. These findings are similar to Hashweh (1987).

*The relationship between CK and PCK*

The results emphasize that good CK has positive influence in student teachers' PCK and through this in effective teaching. Content experts became conscious of students' conceptual difficulties better than content novices. It is very difficult for a content novice to recognise students' misconceptions because of his/her own misconceptions. These results stand in line with the results of Hashweh (1987); Stacey, Helme, Steinle, Baturo, Irwin and Bana (2001) and Halim and Meerah (2002). Student teachers having inaccurate and inadequate knowledge might transfer their own conceptions to their students (Hashweh, 1987) and in this way add students' conceptual difficulties (Even, 1993). In addition content experts could mention more important contents to be learned. They also were able to describe the most important subject matter to be learned. Sanders et al. (1993) got similar result that it is more difficult for content novices to become conscious of the essential topics than for content experts. Content experts chose more direct activities (hands-on-activities and fieldwork) for their lessons to help students to learn the content. The ratio of direct – indirect activities in lesson plans was 18 to 4. It was notable that creative work (drama, making an animation) was totally absent in content expert lesson plans. Primary student teachers chose ten direct and nine indirect activities (drama, manuscript/description of animation, searching knowledge, video presentations and small group discussion). It was amazing however that better content knowledge had no significant effect on student teachers' knowledge on experiments and demonstrations suitable for teaching. Both content experts and content novices had no knowledge on these. This means that at least this part of PCK must be explicitly taught. It does not come from either content knowledge or general pedagogical knowledge.

Lederman and Gess-Newsome (1992) question that the effect is always or primarily that CK affects classroom practice. The effect may also be the opposite way. May be it only means that some minimal level of subject understanding is needed. This view is partly supported by our study. Content experts were more able to handle content structure and students' conceptual problems. However they were not much better in producing topic-specific teaching methods. This supports the view that PCK is a separate domain that should be explicitly taught. The findings that expert teachers become more like novices in areas outside their expertise (Sanders et al., 1993; Hashweh, 1987) also support the former view. This study gives evidence that lesson plans are clearly affected by the level of CK. Because of the research methodology used in this study we cannot say that it affects the real classroom practice.



*Orientation to teaching*

Orientation to teaching science is put in a separate chapter in the discussion, although it was originally treated as a component of PCK according to the classification adopted from Magnusson et al. (1999). However, after this study our position is that it is better to include it to teachers' practical or implicit theory. It is an organizing idea of teaching, which is difficult to change because it is largely implicit and tacit. Teaching orientations are thus seldom deliberately chosen. We think that it is better to restrict the concept of PCK to denote the middle-face in teachers' decision making. The term script (Borko et al., 1990; Putnam 1987,) could also be used as a substitute of PCK, or simply a teacher's pedagogical construct (Hashweh, 2005). We are inclined to use the latter concept.

Student teachers' teaching orientation was connected to their own educational background. Primary teacher training emphasizes student centred learning and they mainly had constructivist teaching orientation. Biology student teachers were more content oriented, but they have a dual experience in their educational history. In their educational studies student centred approaches are emphasized. On the other hand their subject matter studies are almost exclusively teacher centred delivering pure academic knowledge. Their teaching orientations were a combination of constructivist and conceptual orientations. Constructivist orientation was slightly dominating. This could be interpreted in a way that the biology student teachers were in a transition from conceptual to constructivist orientation. According to Adams and Krockover (1997) secondary student teachers' teaching orientation is mostly effected by studies of subject departments where concept mastery approach prevails.

One reason for the use of more student centred approaches by primary student teachers might be that they thus conceal their weaker CK. A slight emphasis on activity-based orientation in primary student teachers might also be explained by concealment of weak CK. This is probably also expressed in a control of interaction in lessons. This view is supported by the finding of Gess-Newsome and Lederman (1995) that primary student teachers used less time on introducing the subject and discussion about it. This is however contrary to the findings of Carlsen (1993) and Sanders et al. (1993) that content novices are most of the time talking during the lessons.

According to the study of Hashweh (1996) constructivist teachers were better aware of students thinking and used a richer variety of teaching strategies. These findings are not supported by our study. The primary teachers were more constructivists but were less aware of student alternative conceptions and did not use a bigger variety of teaching methods.

*Perceived educational needs*

In this study the most common educational need mentioned by the content novices was CK, followed by content specific teaching methods. The content experts felt confident about their CK but felt insecure in knowledge of content specific teaching methods and knowledge on students thinking and understanding of science. For this end they hoped more experience in teaching science in the primary level. What is missing in explicated educational needs is educational theory. This is in line with the findings that pedagogical studies generally have little influence (Adams & Krockover, 1997).

*The reliability of the study*

The purpose of the study was to clarify the effect of CK on PCK. PCK is studied in the context of teachers' thinking and teachers' craft knowledge. When the purpose of the study is to clarify teacher thinking the lesson plan method combined with questionnaires and interviews is an acceptable method. However PCK is valuable concept only if it affects classroom practice. That is why some researchers think that only the studies which use direct classroom observations are valid (Lederman & Gess-Newsome, 1992). However, direct classroom observations have some limitations. The many classroom constraints limit teachers' possibilities and ideas may often remain unrealized. In order to reveal a teacher's PCK thus might need the observation of several lessons in different contexts. Another possibility is to ask the teacher to comment on recorded lessons.

CK is fairly easy to find out because it is explicit. However, PCK is largely tacit and teachers have much difficulty in explicating it (Loughran , Milroy, Berry, Gunstone and Mulhall , 2001). This limits the usefulness of interviews. It is probably easiest to find out while discussing the teaching of a well understood specific topic. The combination of several methods is needed and still it is probable that same aspects of PCK are not revealed. It is especially difficult for the teachers to explicate the deeper pedagogical thinking behind the teaching activities (Loughran et al., 2001). The result categories were fairly easy to form and results were in accord with each other, which supports the validity of the research.

Another question is what the connection between teachers' thinking and classroom practice is. This cannot be answered without classroom observations, but classroom observations have the limitations mentioned above. This is why combinations of lesson plan method and observation of the real teaching would be profitable. This however limits the amount of teachers that can be studied.

## Implications to teacher education

The strength of PCK in teacher education is that it is within the tradition of studying teachers' craft knowledge and teachers' thinking in general (Loughran et al., 2001). We think that PCK has much potential in teacher training, but so far simple enough ways of analysing and representing the knowledge are missing. These should be simple enough to guide the practice, help to rapidly grasp the idea and give simple conceptual tools for lesson planning. In our teaching in Jyväskylä we have used PCK as some kind of check list. On possible approach is offered by Loughran, Mulhall, Berry (2004) and Loughran et.al .,(2001) with their content representation table (CoRe) combined with professional and pedagogical experience repertoire (PaP-eR). This has been used in in-service teacher training. Content representation is well suited to table form and obviously clarifies the content. However there is no form for the aspects of PCK presented in PaP-eRs and it seems to be too complicated for initial teacher training.

Explicit models of PCK ar not extensively used in initial teacher training. Behind this is probably the idea that PCK develops through teaching experience. Research gives support for this view (e.g. Hogan et al., 2003, Clermont, Borko & Crajcik, 1994). A question then arises whether expert behaviour can be directly taught to novices because otherwise expertise is thought to be reached after maybe 10 years. Teaching expert strategies does not guarantee the development of expert behaviour (see the references in the review by Hogan et al. 2003). No such teaching program has been presented and all teacher education programs use a variety of learning experiences during several years after which no one tells that they have produced experts.

We agree with the conclusion of Van Driel, Verloop and De Vos (1998) and Hogan et al. (2003) that an effective means for developing expertise could be the study of different ways of teaching certain central topics. This has been the approach in Jyväskylä University in the science education program for primary school teachers. The core of the program is that students make a study of the teaching of one science topic during one year. Most of the teaching is geared for the support of this project. As far as possible the students are given an opportunity to test their ideas and lesson plans in University's training school. The project includes the content analysis, finding out students' ideas about the topic, finding, selecting or creating the most appropriate presentations and teaching strategies and making a plan for a teaching period of some lessons. We suppose that this experience is at least partly transferable to other situations, but so far we have no empirical evidence for this view.

This research supports the view that PCK should be taught during teacher training. Both primary and secondary student teachers mentioned domain or topic specific teaching methods as one of their main perceived educational needs. As presumed the primary student teachers mentioned the gaps in content knowledge as a major obstacle in lesson planning.

There are some teacher education programs that use PCK as a central concept in their education programs. Zembal-Saul, Starr and Krajcik (1999) have used it in the science teaching unit for primary teachers. They used the classification of teacher knowledge domains according to Magnusson et al. (1999). A similar program for the education of secondary science teachers has been presented by Niess & Scholtz (1999). Results from these and other (Jones & Moreland, 2004; Mason, 1999) research papers show that using PCK as framework has been effective in developing students' thinking and understanding, what effective teaching might be.

There are many different views on the concept of PCK. We hope that future research clarifies the concept and its relationship to related concepts. We need more examples of its' use in teacher training. Especially there is a need to develop simple tools to facilitate initial teacher education.



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Table 1. Activities chosen by primary and secondary student teachers for teaching photosynthesis and plant growth to sixth graders.

| | Primary student teachers (n=10) | Secondary student teachers (n=10) |
|---|---|---|
| *Direct activities* | | |
| Experimental work | 2 | 2 |
| Examining plant structure | 4 | 6 |
| Observing plant growth | 3 | 4 |
| Field work | | |
| | | |
| *Indirect activities* | | |
| Writing manuscript for animation | 1 | 0 |
| Searching information | 4 | 1 |
| Drama | 2 | 0 |
| Watching a video | 0 | 2 |
| Small group discussion | 2 | 1 |

Table 2. A summary of differences found between content novices and content experts

| **The study object** | **Content novices** (primary student teachers) | **Content experts** (secondary student teachers) |
|---|---|---|
| Content knowledge | In most cases more fractured and inadequate, more misconceptions. Connections between concepts not clear. | Usually a more consistent model of explanation with fewer misconceptions. Connections between concepts clearer. |
| Pedagogical content knowledge (PCK): knowledge of students' scientific comprehension | Not aware of students' conceptual problems | Partly aware of students' conceptual problems |
| PCK: Knowledge on the science curriculum | Notice usually fewer relevant matters to learn, describing them is more difficult. | Notice usually a larger number of relevant matters to learn and describe them easier |
| PCK: Knowledge on science teaching methods | Choose more activities through which the content could be learned with indirect methods. The knowledge on experiments and demonstrations is missing. | Choose more activities through which the content could be learned with direct methods. The knowledge on experiments and demonstrations is missing. |
| Orientation to teaching | Mostly constructivist, student-centred | Mostly mixtures of constructivist and conceptual approaches (transitional) |
| Problems in lesson planning | Insufficient content knowledge | Knowledge on students' scientific comprehension, also content knowledge for some. |
| Perceived educational needs | Content knowledge; knowledge on topic specific teaching methods; | Knowledge on topic-specific teaching methods; teaching experience in the primary level |

**Appendix 1**. The interview questions to find out teacher trainees' content knowledge, pedagogical content knowledge, pedagogical problems and educational needs.

The interview questions

1. Where has the mass of the plant come from when it has grown from a small plant to a big one?

2. For what purpose does the plant use the sugar produced? What are the benefits of sugar for the plant?

3. Do you want to comment your answers?

a) Do you have something to add to your answers?

b) Is there something in your answers that you would like to change?

4. How did you experience the writing of lesson plans?

a) What feelings did you have during the planning?

b) Do you think that something was very problematic? Which one?
c) What kind of things did you contemplate when making lesson plans?
Where did you pay attention to?

5. What is the most important thing that you want to teach about the photosynthesis and the plant growth?

a) Why do you think it is important?

b) Are there ant other important things to learn in you lesson? Why do you think they are important?

6. Tell about your lesson plans on photosynthesis and plant growth.

a) Why did you end up in the lesson plan like the one you did?

b) How do your lessons proceed?

c) What else do your lessons include?

7. What new do you think your students will understand after your lessons?

a) Why do you think your students will learn just this?

b) Are there some other things that you think your students will learn? Why do you think your students will learn just that?

8. Let us imagine that you will carry out your lesson plan tomorrow. How would you feel about doing it?

a) What are the strengths of your plan and carrying it out at the moment?

b) Where do think you would pay attention to before the lessons. What would be the other possible things to develop in your lesson plan and its implementation?

c) Do you think that you would face any problems during your lessons? What would they be?

9. What kinds of positive and negative thoughts and feelings are arising when you think teaching of photosynthesis in general?

10. Do you think you would need some extra help and support, when you need to plan and implement your lesson plan (photosynthesis and plant growth)?

a) For which matter in your studies would you need most help and support?

b) For which other matters in your studies would you need more support?

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